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Effect of aluminum chloride and dietary phytase on relative ammonia losses from swine manure[1]

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ABSTRACT: Ammonia (NH_3) losses from swine manure contribute to odor problems, decrease animal productivity, and increase the risk of acid rain deposition. This study was conducted to determine whether aluminum chloride ($AlCl_3$) or dietary manipulation with phytase could decrease relative NH_3 losses from swine manure. Twenty-four pens of nursery pigs were used in two trials, and the pigs were fed normal or phytase-supplemented (500 IU/kg) diets. Aluminum chloride was added to manure pits ($1.9 \times 1.2 \times 0.5$ m) under each pen at 0, 0.25, 0.50, or 0.75% (vol:vol) of final manure volume. Manure pH and NH_3 losses (measured by relative NH_3 flux) were determined twice weekly. The addition of $AlCl_3$ at 0.75% decreased ($P < 0.05$) manure pH from 7.48 to 6.69. Phytase decreased ($P < 0.05$) manure pH to 7.07 compared with 7.12 in the normal diet manure. Aluminum chloride administered at 0.75% without phytase reduced ($P < 0.05$) relative NH_3 losses 52% for the entire 6-wk period. Relative NH_3 losses were decreased ($P < 0.05$) from 109 mg of $NH_3/(m^2 \cdot h)$ in pens containing pigs fed the normal diet without $AlCl_3$ to 81 mg of $NH_3/(m^2 \cdot h)$ in pens housing pigs administered the phytase diet, a 26% reduction. When the phytase diet and 0.75% $AlCl_3$ additions were used in combination, relative NH_3 losses were reduced ($P < 0.05$) by 60% compared with pens of pigs fed the control diet without $AlCl_3$. Decreases in manure pH were likely responsible for the observed reduction in NH_3 losses. Multiple regression was performed with relative rates of NH_3 losses as the dependent variable and rate of $AlCl_3$ addition, diet, and manure pH as independent variables. The model was tested using a stepwise regression ($P < 0.001$), and results indicated that the most important factors determining NH_3 losses were manure pH and diet. However, the contribution of $AlCl_3$ cannot be discounted. When manure pH was regressed against $AlCl_3$ and dietary phytase, $AlCl_3$ levels accounted for 64% of the variation in manure pH ($P < 0.001$). Dietary manipulation with phytase and application of $AlCl_3$ to manure are promising management practices for the reduction of NH_3 from swine facilities.

Key Words: Aluminum Chloride, Ammonia, Phytase, Swine Manure

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Introduction

Swine facilities are under increasing pressure to reduce potential pollution, including nutrient and gaseous (odor) losses. Ammonia losses from swine facilities contribute to odor problems, environmental degradation, and health problems in both animals and humans. ApSimon et al. (1987) suggested that atmospheric NH_3 pollution may play a role in acid rain production, and that the dominant source of NH_3 in Europe was from animal wastes. Ammonia losses also impact animal health and production. High levels of atmospheric NH_3 increase swine susceptibility to respiratory problems from microorganisms such as *Pasteurella multocida* (Neumann et al., 1987), conchal atrophy (Drummond et al., 1981), and atrophic rhinitis (Robertson et al., 1990), and also reduce feed consumption and ADG by pigs (Strombaugh et al., 1969).

Decreasing NH_3 losses through dietary modification or manure amendments could hold many advantages to

[1]Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA and does not imply its approval to the exclusion of other products that may be suitable.

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Table 1. Volumes of expected manure, actual manure production, and $AlCl_3$ added to manure pits for both trials of nursery swine as a function of diet phases

$AlCl_3$ treatment	Expected manure volume, L[a]			Actual manure volume, L			Volume of $AlCl_3$ added, L[b]		
	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
0.00	123	268	423	132	269	445	0.00	0.00	0.00
0.25	123	268	423	131	257	456	0.31	0.67	1.06
0.50	123	268	423	130	258	430	0.62	1.34	2.12
0.75	123	268	423	130	272	417	0.92	2.01	3.17

[a]Values for expected manure volume taken from spreadsheet provided by University of Arkansas Cooperative Extension Service, Little Rock.
[b]Aluminum chloride is approximately 4.6% Al by volume.

swine producers. Inclusion of adipic acid (van Kempen, 2001), increasing dietary carbohydrate levels (Cahn et al., 1998), and reducing CP in diets (James et al., 1999) have all been shown to decrease manure pH and NH_3 volatilization. Manure pH directly affects NH_3 volatilization (O'Hallaron, 1993; Burgess et al., 1998), such that dietary modifications that decrease manure pH will also reduce NH_3 losses. Aluminum sulfate (alum) added to poultry litter reduced litter pH and NH_3 losses by 99% (Moore et al., 1995), which related to improved weight gains and feed conversions, and reduced costs associated with ventilating NH_3 contaminated air (Moore et al., 1999). Alum and $AlCl_3$ were found to reduce swine manure pH significantly (Smith et al., 2001); however, NH_3 losses were outside the scope of that study. The objective of this study was to evaluate the ability of dietary modification with phytase and $AlCl_3$ manure amendments on relative NH_3 losses from swine manure.

Materials and Methods

This study was conducted in a nursery at the University of Arkansas swine farm, with 24 pens measuring 1.8×1.2 m. In each of the two trials, pigs were blocked into three weight groups; each weight group was further divided into eight subgroups of six pigs per pen. The pigs used for this study were bred from Yorkshire × Landrace sows and Hampshire × Duroc boars. Six nursery pigs were randomly assigned to each pen at weaning (approximately 19 d of age and approximately 6.5 kg at weaning). Individual manure analysis from each pen was possible due to the construction of individual manure collection pits under each pen. The manure pits were constructed from stainless steel and were $1.9 \times 1.2 \times 0.5$ m. A pull/plug manure management system with a 2-wk flush cycle was used to manage the manure. Lagoon water was pumped into each pit at the beginning of the flush cycle, at which time $AlCl_3$ additions were made. Aluminum chloride treatment volumes were based on estimated manure production volumes from spreadsheets obtained from the University of Arkansas Cooperative Extension Service and verified using existing data from these pens (Table 1).

A 4×2 factorial design was used with four levels of $AlCl_3$ and two levels of phytase, such that there were three replications of each treatment in each of the two trials. Aluminum chloride was added to manure pits at 0, 0.25, 0.50, and 0.75% $AlCl_3$ on a volumetric basis determined by the estimated final manure volume for each flush cycle. Estimated and actual manure volumes produced in each 2-wk phase and $AlCl_3$ application rates by phase are noted in Table 1. The high level of $AlCl_3$ treatment was based on a 1:1 molar ratio of P:Al, because reducing P solubility and P runoff are documented benefits of $AlCl_3$ use in swine manure (Smith et al., 2001). There were two phytase treatments: 1) normal diet without phytase based on NRC (1998) recommendations for all nutrients using available P (**aP**) values; and 2) phytase diet based on NRC aP minus 0.1%, with phytase mixed into feed after pelleting at 500 U of phytase/kg of feed.

A three-phase diet system was used in this study, and pigs were fed dietary treatments throughout phase 1 (d 0 to 14 after weaning), phase 2 (d 14 to 28 after weaning), and phase 3 (d 28 to 42 after weaning). Diet change and pit flush/recharge occurred at the same time. Both trials ended at the end of the sixth week. Diets for each phase were the same for both trials and are noted in Table 2.

Ammonia losses (as measured by relative NH_3 flux) from manure, manure pH, and foam pH were measured in-situ, twice weekly. For NH_3 flux measurements, the SCAT-30 method (Moore et al., 1997) was modified for this study due to strict space limitations. An electrochemical NH_3 sensor (model E/C-P1-NH_3, Manning Systems, Lenexa, KS) was attached to a chamber that measured $21.9 \times 21.9 \times 7.0$ cm (Figure 1) and floated on the manure surface. Air circulated through the enclosed system at a rate of 2.5 L/min using a modified aquarium pump. Ammonia concentrations were measured at 0, 10, 30, 60, 90, 120, and 150 s following chamber placement on the manure surface, which was not sufficient time to change the manure or air temperature inside the chamber. However, air and manure temperature were monitored continuously throughout each set of measurements. Only one chamber was used to minimize differences that could exist between different chambers. Between measurements of different manure pits, 2 to 5 min lapsed in order to ensure adequate time for the air inside the flux chamber and air pump to

Table 2. Composition of Phase 1 (d 0 to 14), Phase 2 (d 14 to 28), and Phase 3 (d 28 to 42) diets fed to weanling pigs on (as-fed basis)

	Phase 1		Phase 2		Phase 3	
Item, %	Normal	Phytase	Normal	Phytase	Normal	Phytase
Yellow corn	42.54	42.77	45.17	45.43	61.30	61.56
Lactose	18.00	18.00	10.10	10.10	—	—
Soybean meal, 48% CP	—	—	36.00	36.00	31.50	31.50
Soy protein concentrate	10.00	10.00	—	—	—	—
Processed soy protein[a]	10.25	10.25	—	—	—	—
Spray-dried blood cells[b]	2.00	2.00	1.00	1.00	—	—
Spray-dried plasma protein b	4.00	4.00	—	—	—	—
Select menhaden fish meal	6.00	6.00	—	—	—	—
Soybean oil	4.00	4.00	4.00	4.00	4.00	4.00
Ethoxyquin	0.03	0.03	0.03	0.03	0.03	0.03
Lysine HCl	0.15	0.15	0.14	0.14	0.15	0.15
Threonine	0.13	0.13	0.08	0.08	0.04	0.04
Isoleucine	0.10	0.10	—	—	—	—
Methionine	0.18	0.18	0.12	0.12	0.04	0.04
Antibiotic premix[c]	0.10	0.10	0.10	0.10	0.125	0.125
Mineral premix[d]	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[e]	0.25	0.25	0.25	0.25	0.25	0.25
Copper sulfate	0.07	0.07	0.07	0.07	0.07	0.07
Zinc oxide	0.25	0.25	0.245	0.245	0.245	0.245
Dicalcium phosphate	0.60	0.05	1.35	0.80	0.85	0.30
Calcium carbonate	0.70	1.02	0.70	1.00	0.75	1.05
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Phytase, IU/kg of feed[f]	—	500	—	500	—	500

[a]Optipro (Land O'Lakes, Inc., Fort Dodge, IA).
[b]Spray-dried blood cells: AP-301; spray-dried plasma protein: AP-920 (American Protein Corp., Ames, IA).
[c]Provided 0.15 g of neomycin as neomycin sulfate and 0.11 g of oxytetracline/kg of feed from d 0 to 28 postweaning, and 0.11 g tylosin/kg of feed from d 28 to 42 postweaning.
[d]Supplied 0.30 mg of Se, 40 mg of Mn, 165 mg of Zn, 165 mg of Fe, 17 mg of Cu, and 0.30 mg of I/kg of feed.
[e]Supplied 11,023 IU of vitamin A, 1,653 IU of vitamin D_3, 44 IU of vitamin E, 4.4 mg of vitamin K, 33 mg of pantothenic acid, 55 mg niacin, 10 mg of riboflavin, and 44 μg of vitamin B_{12}/kg of feed.
[f]Phytase was sprayed on pellets to administer 500 IU of phytase/kg of the treatment diet.

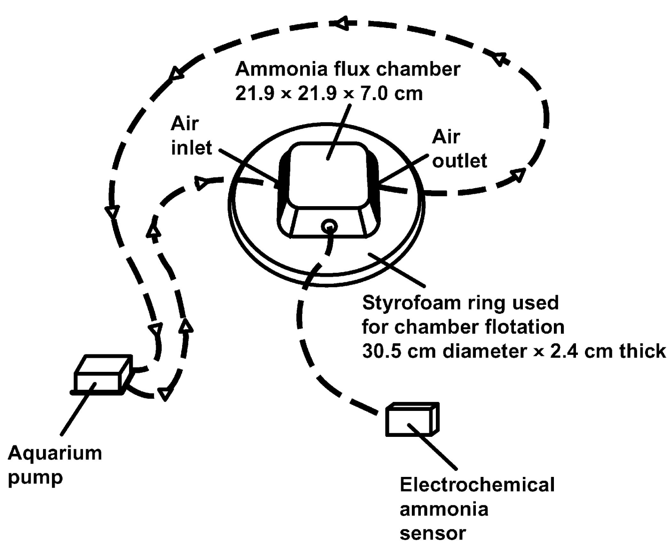

Figure 1. Drawing of the enclosed chamber used to make ammonia flux calculations from the surface of swine manure.

reach background levels. From these NH_3 measurements, relative flux calculations were made using the ideal gas law (Moore et al., 1997). The chamber method used was required due to the mixed atmosphere in the production facility and the space limitations of each manure pit. Manure pH and foam pH were measured at the same time as flux measurements (Piccolo 2, Hanna Instruments, Pardova, Italy). At the end of each diet phase in both trials, all manure in each pit was homogenized for 5 min and manure samples were collected and analyzed for total N using a Skalar FORMACS HT analyzer (Skalar Analytical, Breda, The Netherlands).

Statistics were performed using the GLM and stepwise regression procedures in SAS v. 8.2 (SAS Inst., Inc., Cary, NC) for the treatment main effects and significant interactions of all measurements taken for pH and NH_3 flux. Further statistical analysis was performed to determine the effects of time on the variables. Manure pH and relative NH_3 losses as measured across days of the flush cycle were analyzed as a split plot across time using the mixed model procedure of SAS with weight block × treatment as the random variable. An *a priori* level of 0.05 was selected for significance in analyses. Means were separated using Fishers least significant difference method in SAS.

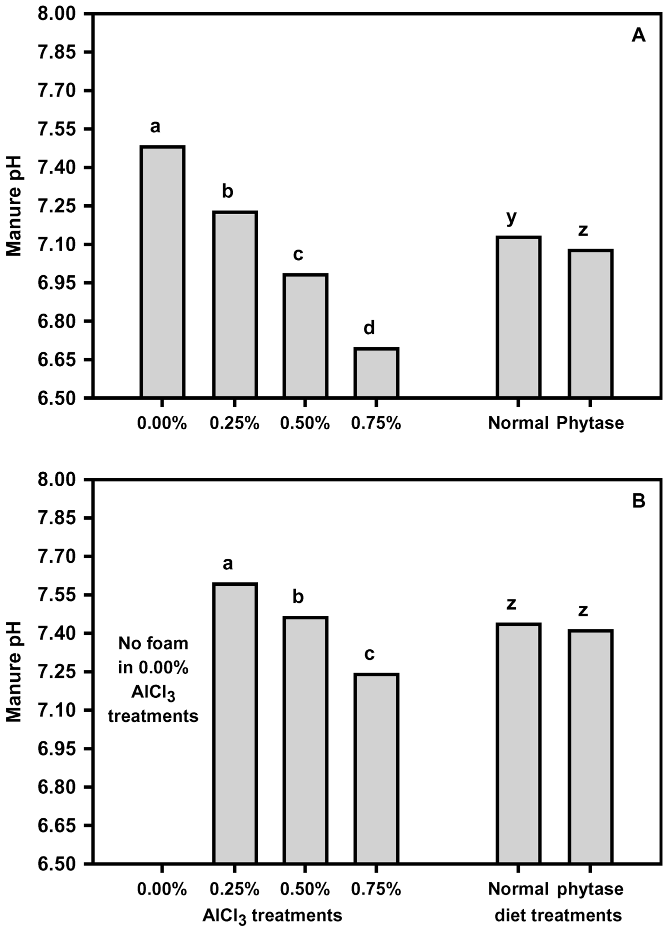

Figure 2. Effects of aluminum chloride added to manure (vol:vol, based on estimated final manure volume) and dietary phytase (500 IU/kg feed) on manure (A) and foam (B) pH. Means without a common letter differ, $P < 0.05$. Bars in each treatment represent a mean of 144 and 288 $AlCl_3$ and dietary phytase measurements, respectively.

Results and Discussion

Decreases in pH and Ammonia Losses

The treatment main effects of $AlCl_3$ and dietary phytase addition on manure and foam pH are reported in Figure 2 (phytase × $AlCl_3$ interaction; $P > 0.10$). The addition of $AlCl_3$ reduced ($P < 0.01$) manure pH from 7.48 in the control pits to 6.69 in the manure pits containing 0.75% $AlCl_3$ (Figure 2A). Phytase diets reduced ($P < 0.05$) manure pH from 7.12 in the normal diet to 7.07. When manure pH was regressed against the $AlCl_3$ treatment level and dietary phytase, $AlCl_3$ rates accounted for 64% of the variation in manure pH ($P < 0.001$; Table 3). Using stepwise procedures, dietary phytase was not found to be sufficient to enter into the model ($P > 0.15$).

As Al^{3+} is added to solution, hydrolysis occurs, forming $Al(OH)_3$ and releasing 3 H^+, thereby reducing solution (manure) pH. The reasons for pH reduction with dietary phytase are not as clear-cut. It is not known whether the pH reduction was the result of the actual phytase inclusion in the diet or a change in chemistry due to reductions in dicalcium phosphate levels in the diet. Although the latter of these explanations would likely account for the bulk of the pH reduction, there is no evidence to indicate that phytase does or does not directly contribute to the pH reduction. As was seen in an earlier study (Smith et al., 2001) when $AlCl_3$ was added to swine manure, foam formed on the surface, probably resulting from $CaCO_3$ dissolution. This hypothesis is supported by the fact that titratable alkalinity was inversely proportional to the level of $AlCl_3$ treatment (data not shown). The foam was extremely dense and lasted for a period of 12 d. It has been suggested that this foam may act as a barrier to gaseous losses (Smith et al., 2001), but this was not measured in the current study. As with manure pH, foam pH decreased ($P < 0.001$) with increasing levels of $AlCl_3$ addition to manure (Figure 2B). Smith et al. (2001) observed a foam pH around 5.0, whereas in this study, the pH ranged from about 7.2 to 7.6. Although the reason for the discrepancy in foam pH is not clearly understood, the diets, which alter manure and thus foam chemistry, were not documented in the previous study.

As was expected, addition of $AlCl_3$ to manure reduced ($P < 0.001$) relative NH_3 losses (Figure 3), such that increasing the amount of $AlCl_3$ resulted in greater reductions in NH_3 losses. Aluminum chloride at the 0.75% level, without dietary phytase, reduced ($P < 0.001$) relative NH_3 losses from 109 mg of $NH_3/(m^2 \cdot h)$ (control pens) to 52 mg of $NH_3/(m^2 \cdot h)$, a 52% reduction for the entire 6-wk period. Phytase diets without $AlCl_3$ added to manure also reduced ($P < 0.01$) relative NH_3 losses compared with normal diets from 109 mg of $NH_3/(m^2 \cdot h)$ in the control pens to 81 mg of $NH_3/(m^2 \cdot h)$ (Figure 3). This is the first study to show that use of phytase and/or reduction of P supplementation can decrease NH_3 losses from swine manure. When the phytase diet and $AlCl_3$ manure additions were used in combination at the 0.75% rate of $AlCl_3$, relative NH_3 losses were decreased (phytase × $AlCl_3$ interaction; $P < 0.10$) compared with the control diet without $AlCl_3$. Numerical reductions ($P > 0.10$) in relative NH_3 losses were noted when comparing phytase-supplemented diets with normal diets within 0.50 and 0.75% $AlCl_3$ treatments to manure. Although this decrease was not significant statistically, the use of these best management practices (**BMP**) together could help producers reduce NH_3 losses more than if either $AlCl_3$ or dietary phytase treatment was used alone. In addition, the combination of these BMP also reduces total P and P solubility in swine manure, providing further benefit to the environment (our unpublished results).

Relative NH_3 losses were significantly related ($P < 0.001$) to manure pH (Table 3). The ammonia equilibrium equation shows the relationship to pH; as more H^+ ions are released in solution (pH decrease) the ammonia

Table 3. Multiple regression equations from stepwise regression for manure pH, relative NH_3 loss, total N concentration, and total N mass

Dependent Variable	Model	Model R^2	Partial R^2	*P*-value
Manure pH	= 7.49 – 1.02($AlCl_3$)	0.64		<0.001
Relative NH_3 loss	= –364 + 61.6(Manure pH) – 0.0179(Phytase)	0.43		<0.001
	Manure pH		0.41	<0.001
	Phytase		0.02	<0.05
Total N concentration	= 4485 –294(Manure pH)	0.03		<0.05
Total N mass	= 2819 – 3.96(Relative NH_3 Loss) – 417($AlCl_3$) – 246(Manure pH)	0.25		<0.001
	Relative NH_3 loss		0.20	<0.001
	$AlCl_3$		0.03	<0.05
	Manure pH		0.02	<0.05

equilibrium shifts from volatile NH_3 to nonvolatile ammonium (NH_4^+):

$$NH_4^+ \leftrightarrow NH_3 + H^+$$
$$pKa = 9.25$$

Multiple regression analysis suggested manure pH and diet were the most important factors determining relative ammonia losses (Table 3). Addition of $AlCl_3$ to manure was not important for this model. However, $AlCl_3$ additions were most likely accounted for in the manure pH because $AlCl_3$ accounted for 64% of the variation in manure pH (Table 3).

Effect of Time on pH and NH_3 Losses

During each flush cycle, mean pH and relative NH_3 fluxes showed similar trends with time (Figure 4). The effects of $AlCl_3$ addition on manure pH and NH_3 losses were the greatest immediately after treatment and diminished with time ($AlCl_3$ × day interaction; $P < 0.001$; Figure 4). Over time, swine manure and urine were deposited in the pits, raising ($P < 0.05$) manure pH from 6.4 at the beginning of the flush cycle to slightly above

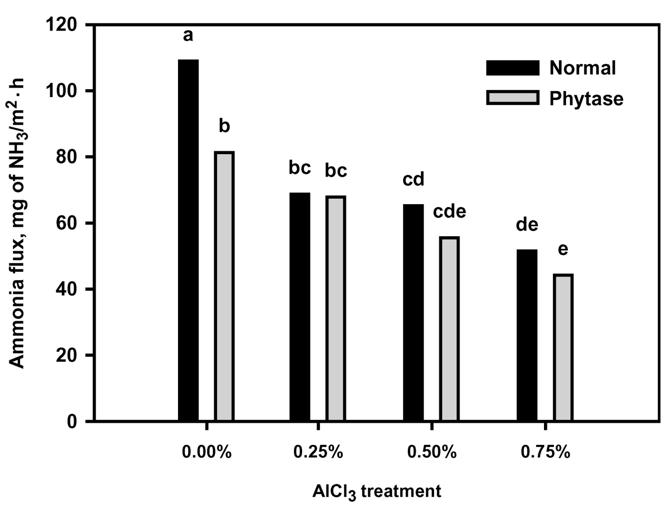

Figure 3. Effect of dietary phytase (added to feed at 500 IU/kg) and aluminum chloride manure amendments (vol:vol based on estimated final manure volume) on ammonia flux from swine manure. Means without a common letter differ, $P < 0.05$. Bars in each treatment represent a mean of 72 measurements.

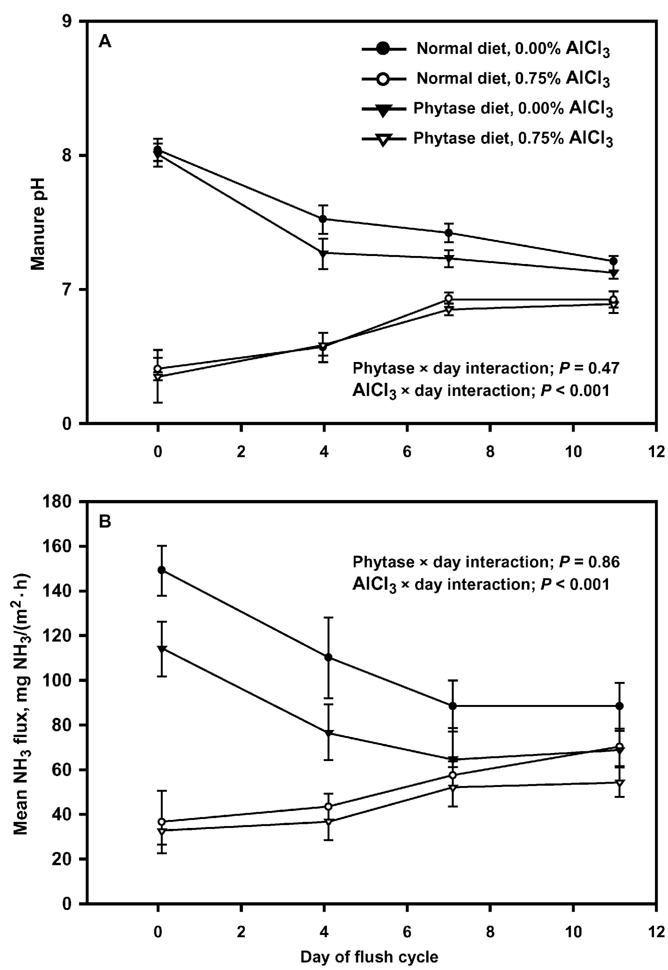

Figure 4. Mean manure pH (A) and ammonia flux (B) as a function of time within the flush cycle (bars represent standard error). Each point is the mean of 18 measurements. For clarity, only control and 0.75% $AlCl_3$ treatments are presented.

6.9 on d 11 in manure from 0.75% $AlCl_3$-treated pens with the normal diet. The effects of dietary phytase on manure pH, although following the same trend as manure from pigs fed the normal diet, resulted in a lower ($P < 0.05$) pH throughout the flush cycle. This might be expected because the root cause of the relative NH_3 reductions is a reduction in manure pH at the source (less dicalcium phosphate in the feed).

Whereas relative NH_3 losses resulting from $AlCl_3$ treatments were initially lower ($P < 0.05$) in treated pens compared with the control $AlCl_3$ treatment, this effect diminished with time, particularly at d 7 and 11 of the flush cycle ($AlCl_3$ × day interaction; $P < 0.001$; Figure 4B). Aluminum chloride (0.75% treatment) without phytase decreased ($P < 0.001$) relative NH_3 losses from 149 to 36.6 mg of $NH_3/(m^2 \cdot h)$ on d 0, a 75% initial reduction. Changes in relative NH_3 fluxes taken on d 7 to 11 for most treatments had leveled off. Hence, decreasing the length of the flush cycle to 1 wk would likely improve the overall effectiveness of reducing NH_3 losses. Many swine operations that use pull/plug systems to manage manure use a 1-wk flush cycle, which could potentially show greater reductions than the 2-wk flush cycle used in this study. The 2-wk cycle used in this study was required because not enough manure was produced in the first 3 wk of either trial to properly dispose of, or sample, the manure. Greater NH_3 reductions near the time of treatment is consistent with data from commercial broiler houses treated with aluminum compounds (Moore et al., 1999), where the majority of NH_3 reduction occurred in the first 4 wk of the 6-wk growing period.

As with manure pH, reductions in relative NH_3 losses due to phytase were more consistent with time, indicating that there was not a significant interaction between the phytase diet treatment and time (phytase × day interaction; $P = 0.86$). The initial reduction ($P < 0.01$) in NH_3 losses using phytase diets compared with the normal diet and no $AlCl_3$ was 23%, whereas the relative reduction ($P < 0.01$) between these two treatments at the final reading of each phase was 22%. The lack of a significant interaction between phytase and time indicates that the effects of NH_3 reduction due to the diet treatments was not affected by time, which was not the case with the $AlCl_3$ manure treatments ($AlCl_3$ × day interaction; $P < 0.001$), where the effects did significantly diminish with time. This is an important point and should be verified by other researchers. Reducing NH_3 losses from poultry litter improved the ambient NH_3 levels within poultry facilities sufficiently to improve ADFI, ADG, mortality, and morbidity (Moore et al., 1999). Reducing atmospheric NH_3 levels inside the rearing facility could increase swine productivity. Productivity measurements resulting from altered ambient levels of NH_3 were outside the scope of the current study due to the mixed atmosphere in the nursery, where all 24 pens were in the same room. Increased weight gains and feed conversions might be expected to result from these treatments due to their ability to reduce NH_3 losses, and in turn, atmospheric NH_3 levels. Taking these technologies to commercial production facilities to test this hypothesis is the next logical step for these technologies.

Nitrogen Retention in Manure

The chambers used in this study were intended to show relative differences in NH_3 loss, and not necessarily to calculate cumulative or annual N losses. However, total N retained in the manure at the end of the 6-wk growing period was significantly related to relative NH_3 loss ($P < 0.001$), rate of $AlCl_3$ treatment ($P < 0.05$), and manure pH ($P < 0.05$; Table 3). The parameters explained 25% of the variability in total N mass, with relative NH_3 loss explaining 20% independently.

Implications

Use of dietary phytase and aluminum chloride manure amendments decreased manure pH and ammonia losses. These management practices could be effective at decreasing ambient ammonia levels, which in commercial facilities, should also translate to improved production as measured by feed intake, average daily gain, and reduced susceptibility to respiratory ailments. Combinations of these management practices could aid producers in waste application when manure application rate is based on the nitrogen content of the manure. The next logical progression for this research is to compare the effects of these treatments in different swine rearing facilities under the same management. This would provide data to determine whether the relative ammonia reductions noted here translate into actual reductions in ambient ammonia levels within the facility, as well as whether these potential reductions could increase productivity and reduce respiratory ailments in swine.

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